

# **OVERSET GRID METHODS APPLIED TO NONLINEAR POTENTIAL FLOWS**

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# OBJECTIVES

- GENERAL: TO DEVELOP CHIMERA-BASED FULL POTENTIAL METHODOLOGY WHICH IS COMPATIBLE WITH OVERFLOW AND OVERFLOW INFRASTRUCTURE -- CREATING OPTIONS FOR AN ADVANCED PROBLEM SOLVING ENVIRONMENT
- MOTIVATION: TO SIGNIFICANTLY REDUCE TURNAROUND TIME FOR AERODYNAMIC ANALYSIS AND DESIGN (PRIMARILY CRUISE CONDITIONS)

# **NUMERICAL APPROACH**

**J. OF AIRCRAFT, VOL. 35, MAY-JUNE 1998**

- **GOVERNING EQUATION: CONSERVATIVE FULL POTENTIAL EQUATION MAPPED TO CURVILINEAR COORDINATES**
- **SPATIAL DIFFERENCING SCHEME:**
  - ◆ **SUBSONIC FLOW: CENTRAL DIFFERENCING (2<sup>ND</sup>-ORDER ACCURATE)**
  - ◆ **SUPERSONIC FLOW (TWO OPTIONS):**
    - ✦ **1<sup>ST</sup>-ORDER UPWIND**
    - ✦ **2<sup>ND</sup>-ORDER UPWIND USING A SOLUTION LIMITER**
- **ITERATION SCHEME: AF2 FULLY IMPLICIT**
- **GRID GENERATION:**
  - ◆ **CARTESIAN GRIDS**
  - ◆ **HYPGEN GRIDS**
- **BOUNDARY CONDITIONS:**
  - ◆ **FLOW TANGENCY AT WING SURFACE AND SYMMETRY PLANE**
  - ◆ **OUTER BOUNDARY FIXED AT FREESTREAM**
  - ◆ **ZERO-SLOPE ON CORRECTION AT OUTFLOW**
  - ◆ **USUAL VELOCITY POTENTIAL JUMP AT VORTEX SHEET**

# **NUMERICAL APPROACH**

**GOVERNING EQUATIONS:** CONSERVATIVE FULL POTENTIAL EQUATION MAPPED FROM PHYSICAL DOMAIN  $(X, Y, Z)$  TO COMPUTATIONAL DOMAIN  $(\xi, \eta, \zeta)$

$$\xi = \xi(X, Y, Z)$$

$$\eta = \eta(X, Y, Z)$$

$$\zeta = \zeta(X, Y, Z)$$

**SPATIAL DIFFERENCING SCHEME:**

- > SUBSONIC FLOW: CENTRAL DIFFERENCING (SECOND-ORDER ACCURATE)
- > SUPERSONIC FLOW (TWO OPTIONS):
  - FIRST-ORDER UPWIND
  - SECOND-ORDER UPWIND USING A SOLUTION LIMITER

**ITERATION SCHEME**

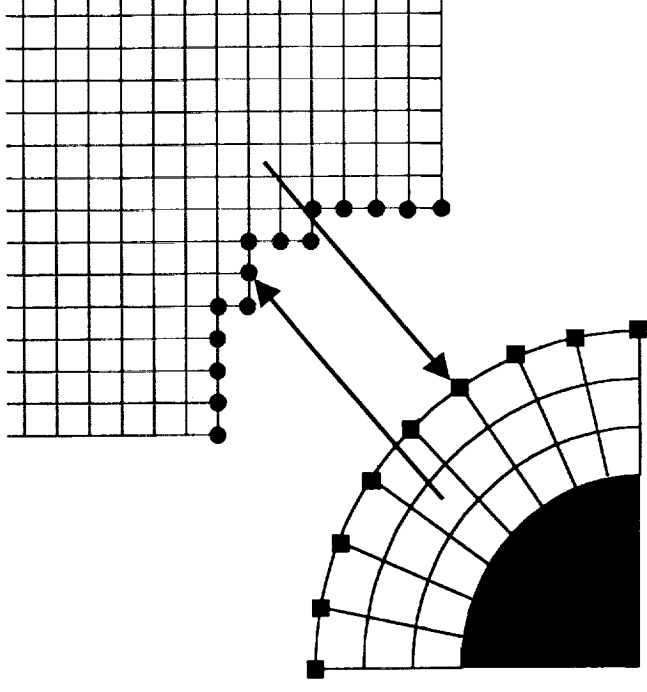
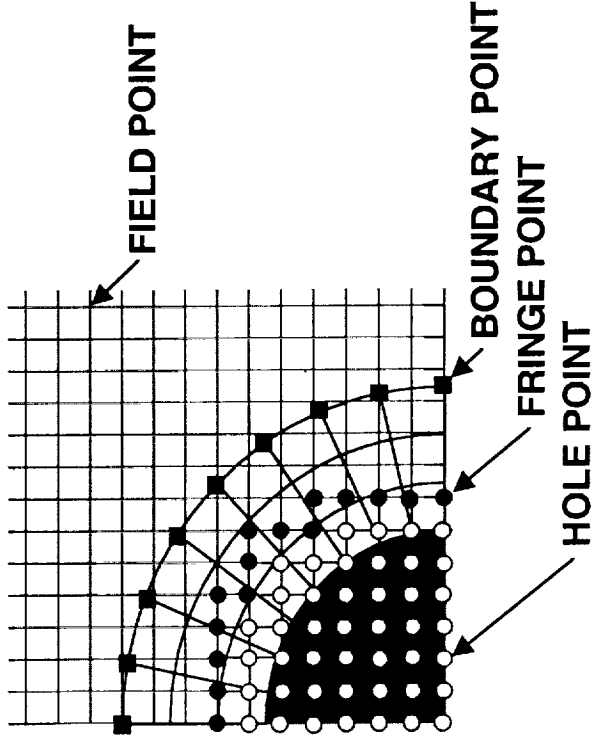
- > AF2 FULLY IMPLICIT SCHEME UTILIZED, BALLHAUS-STEGER (1975)
- > SPECIAL MODIFICATION FOR C-GRIDS: ONE VERSION ABOVE WING, ANOTHER BELOW, CONNECTED AT WING LE USING LOCAL ITERATION

**BOUNDARY CONDITIONS**

- > FLOW TANGENCY AT WING SURFACE AND SYMMETRY PLANE
- > OUTER BOUNDARY FIXED AT FREESTREAM
- > ZERO-SLOPE ON CORRECTION AT OUTFLOW
- > USUAL VELOCITY POTENTIAL JUMP AT VORTEX SHEET

# CHIMERA ALGORITHM FEATURES

- GRID POINTS THAT LIE INSIDE SOLID BODIES ARE FLAGGED USING IBLANK ARRAY
  - IBLANK=1 AT FIELD POINTS
  - IBLANK=0 AT HOLE AND FRINGE POINTS
- IBLANK ARRAY MODIFICATIONS MADE IN SPATIAL AND ITERATION SCHEMES AS APPROPRIATE
- TRI-LINEAR INTERPOLATION OF VELOCITY POTENTIAL USED AT ALL CHIMERA GRID INTERFACES
- DENSITY VALUES AT FRINGE POINTS EXTRAPOLATED FROM GRID INTERIOR



# **FRINGE POINT UPDATE PROCEDURE**

## **(TWO-ZONE GRID)**

- **OLD BOUNDARY CONDITION:**
  - ♦ **UPDATE 1ST GRID ZONE**
  - ♦ **UPDATE 2ND GRID ZONE FRINGE POINTS VIA INTERPOLATION (RESULTS ARE DIRECTLY LOADED INTO VELOCITY POTENTIAL ARRAY)**
  - ♦ **UPDATE 2ND GRID ZONE (CORRECTION VALUES FOR IBLANK=0 POINTS ARE ZERO)**
  - ♦ **ETC**
- **NEW BOUNDARY CONDITION:**
  - ♦ **UPDATE 1ST GRID ZONE**
  - ♦ **UPDATE 2ND GRID ZONE FRINGE POINTS VIA INTERPOLATION (RESULTS ARE LOADED INTO SPECIAL CORRECTION ARRAY)**
  - ♦ **UPDATE 2ND GRID ZONE (FOR IBLANK=0 POINTS SPECIAL CORRECTION ARRAY IS USED TO SET MATRIX COEFFICIENTS)**
  - ♦ **ETC**
- **NEW BC FRINGE POINT VALUES ARE FELT BY EACH GRID POINT IN MATRIX INVERSION, AND THUS, SCHEME'S IMPLICITNESS IS GREATLY IMPROVED**

# HOLE CUTTING AND DONOR CELL SEARCH

- HOLE CUTTING APPROACH
  - ◆ IDENTIFY “DEFINING SURFACE”, E.G., WING OR FUSELAGE
  - ◆ IDENTIFY “MINIMUM BOX” THAT SURROUNDS “DEFINING SURFACE”
  - ◆ USE “DOT-PRODUCT TEST” FOR EACH POINT IN A NEIGHBORING GRID ZONE
    - ✦ IF POINT IS IN MINIMUM BOX IBLANK=0
    - ✦ OTHERWISE IBLANK=1
- DONOR CELL SEARCH ALGORITHM (AIAA PAPER 97-2259)
  - ◆ DIFFERENTIAL EQUATION NUMERICALLY SOLVED FOR LOCATION OF DONOR CELL
  - ◆ APPROXIMATE APPROACH THAT USES NEAREST NEIGHBOR CELL IF ACTUAL DONOR CELL NOT FOUND
  - ◆ VERY FAST (UP TO 60,000 FOUND DONOR CELLS PER SEC)

# DONOR CELL SEARCH ALGORITHM

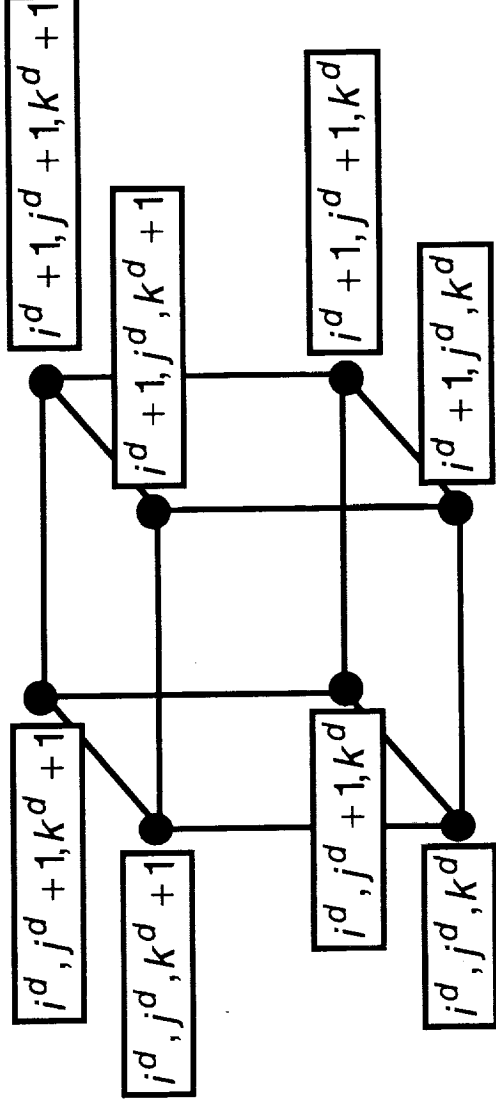
## PROBLEM STATEMENT

GIVEN LOCATION OF ARBITRARY IGBP (INTERGRID BOUNDARY POINT)

$$x^r, y^r, z^r$$

FIND THE THREE INDICES  $i^d, j^d, k^d$  THAT DEFINE THE CELL SURROUNDING  
 $x^r, y^r, z^r$

THIS "DONOR CELL" IS DEFINED BY THE  $x, y, z$  VALUES AT THE FOLLOWING 8 POINTS:





# DONOR CELL SEARCH ALGORITHM

## BASIC IDEA

RELATIONAL INFORMATION BETWEEN COMPUTATIONAL DOMAIN  $(\xi, \eta, \zeta)$  AND PHYSICAL DOMAIN  $(x, y, z)$

$$d\xi = \xi_x dx + \xi_y dy + \xi_z dz$$

$$d\eta = \eta_x dx + \eta_y dy + \eta_z dz$$

$$d\zeta = \zeta_x dx + \zeta_y dy + \zeta_z dz$$

USE NUMERICAL APPROXIMATION TO COMPUTE DONOR CELL LOCATION

$$i^d - i^n = \xi_x^n (x^r - x^n) + \xi_y^n (y^r - y^n) + \xi_z^n (z^r - z^n)$$

$$j^d - j^n = \eta_x^n (x^r - x^n) + \eta_y^n (y^r - y^n) + \eta_z^n (z^r - z^n)$$

$$k^d - k^n = \zeta_x^n (x^r - x^n) + \zeta_y^n (y^r - y^n) + \zeta_z^n (z^r - z^n)$$

$\xi_x^n, \xi_y^n, \dots$  STANDARD NUMERICALLY EVALUATED METRICS

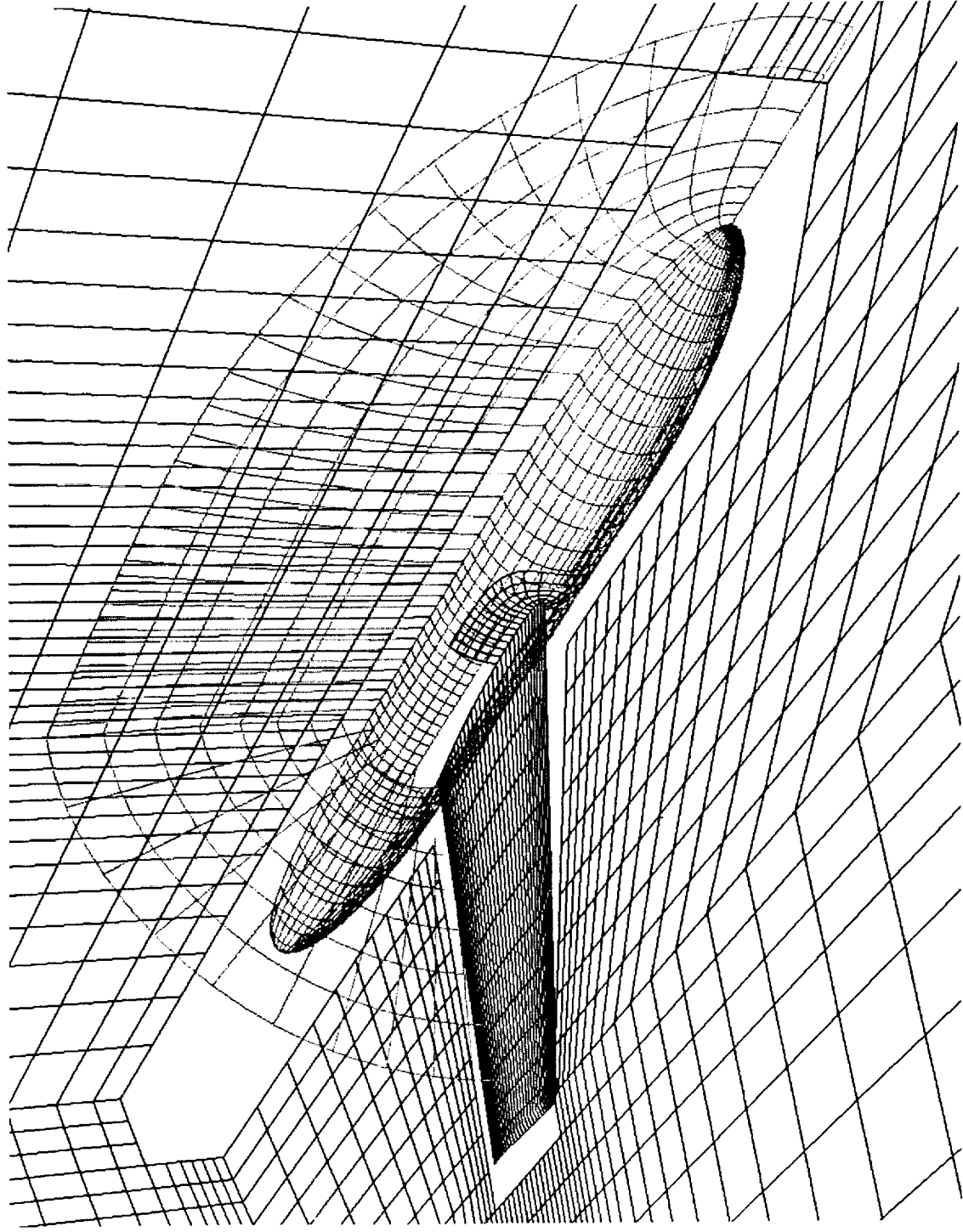
$x^n, y^n, z^n$  ARBITRARY STARTING POINT IN THE DONOR GRID

DONOR CELL CONVERGENCE CRITERIA (EG, LOOKING AT JUST  $i$ )

$$|\xi_x^n (x^r - x^n) + \xi_y^n (y^r - y^n) + \xi_z^n (z^r - z^n)| \leq 0.5 + \text{TOL}$$

# EXPANDED VIEW OF THREE-ZONE GRID

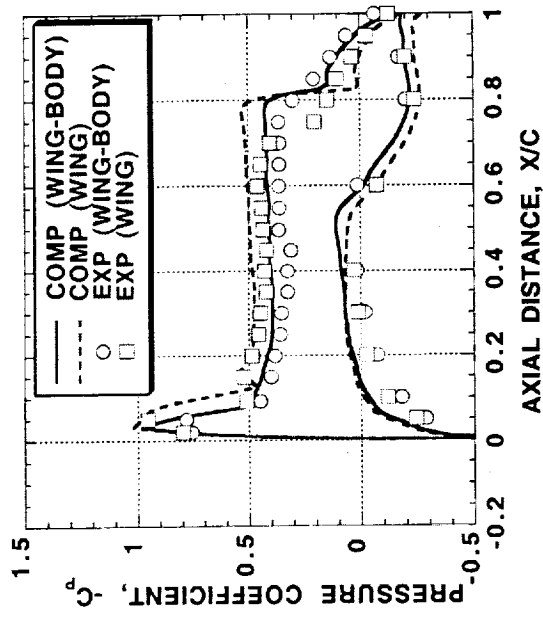
Hinson-Burdges wing B mid-mounted onto a  
blunt-nose cylindrical-cross-section body



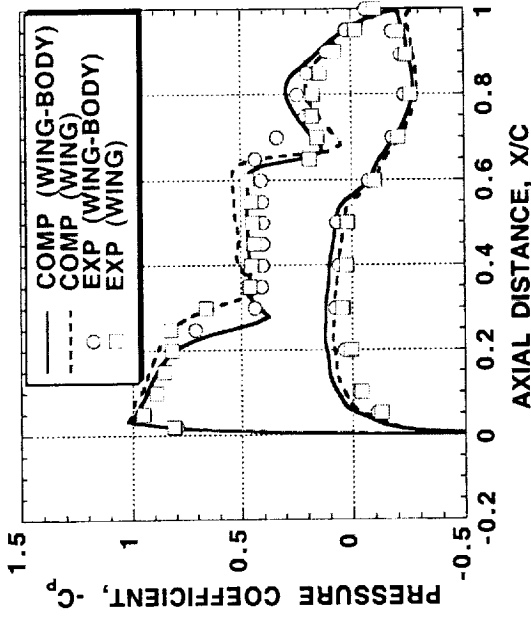
# **PRESSURE COMPARISONS SHOWING EFFECT OF FUSELAGE ON WING SURFACE SOLUTION**

$M_\infty = 0.88$ ,  $\alpha = 2.4^\circ$ .

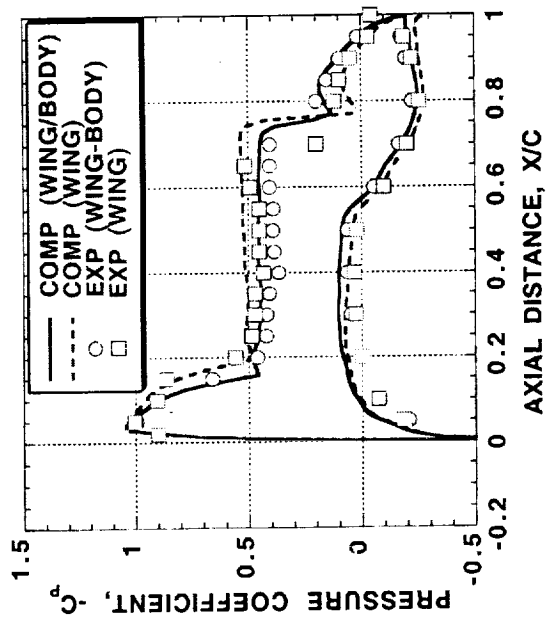
$y/b=0.22$



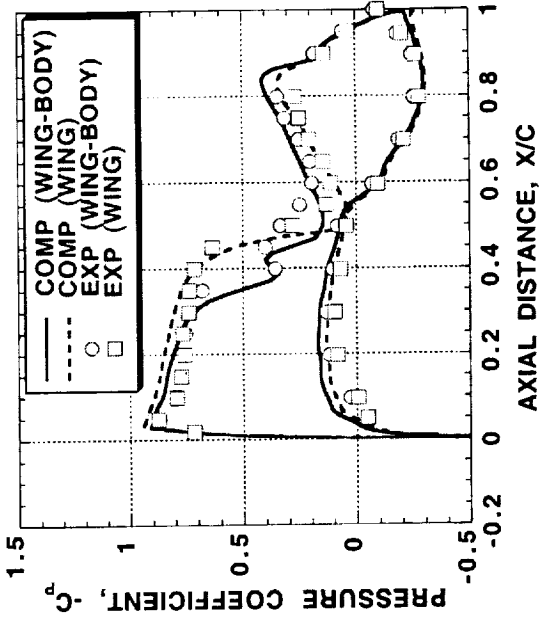
$y/b=0.60$



$y/b=0.40$



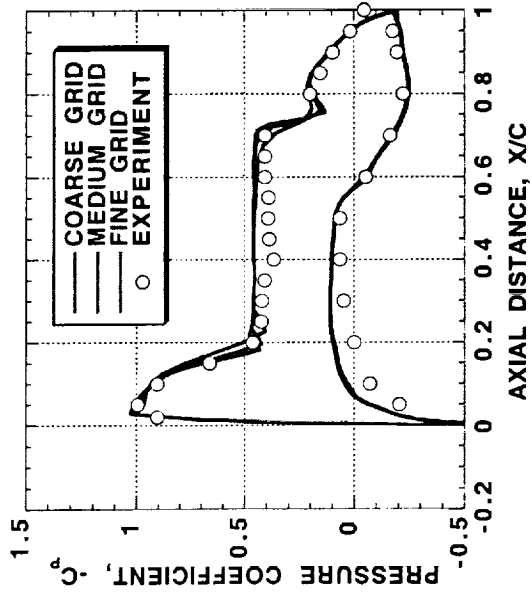
$y/b=0.80$



# PRESSURE COMPARISONS SHOWING EFFECT OF GRID REFINEMENT

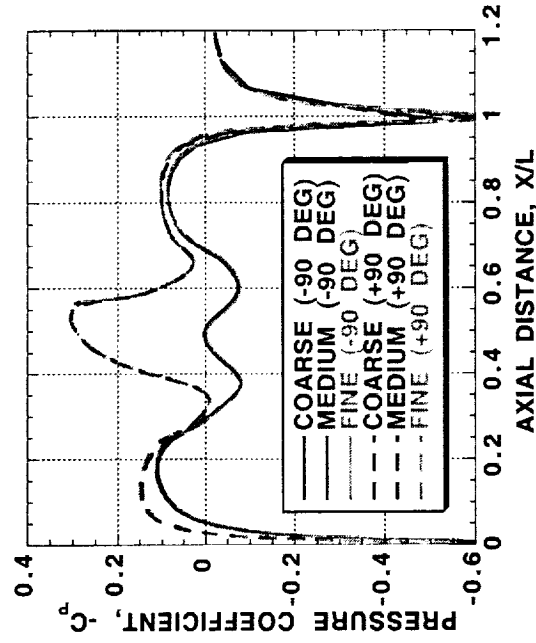
$$M_{\infty} = 0.88, \alpha = 2.4^{\circ}$$

Wing Surface

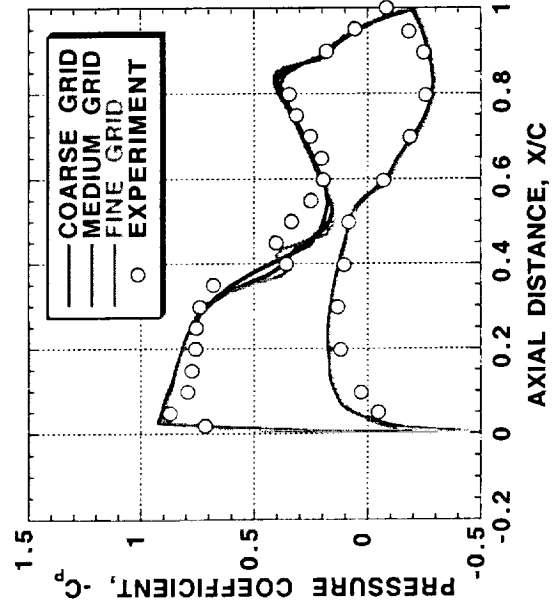


$$y/b=0.40$$

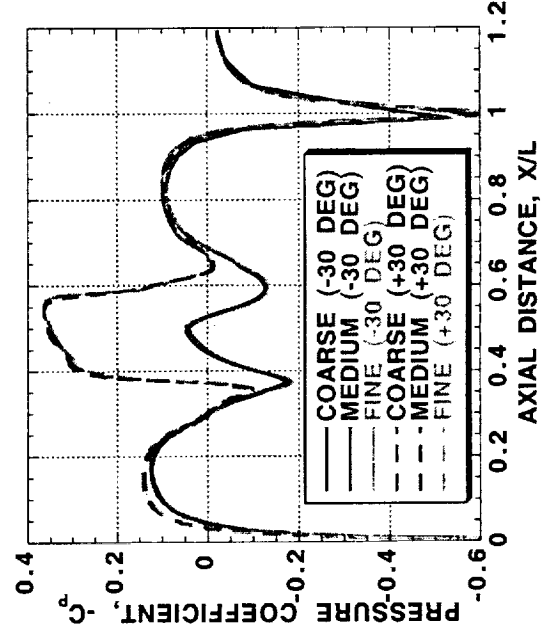
Fuselage Surface



Meridinal  
Angles of  
 $\pm 90^{\circ}$



$$y/b=0.80$$

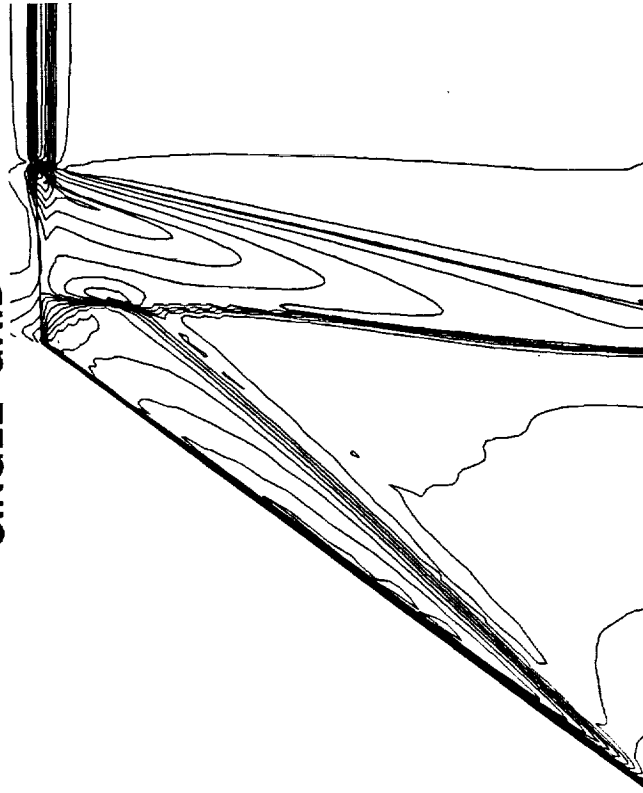


Meridinal  
Angles of  
 $\pm 30^{\circ}$

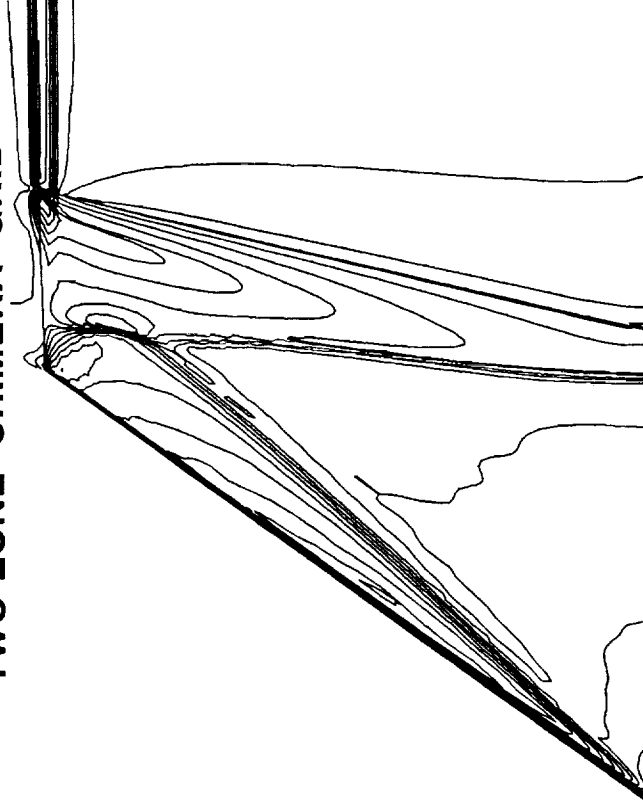
**MACH NUMBER CONTOURS  
UPPER WING SURFACE  
SECOND-ORDER SCHEME, WING B GEOMETRY**

$M_\infty = 0.88, \alpha = 2.4^\circ, \Delta M_\infty = 0.02, \Delta \alpha = 1.5^\circ$

**SINGLE GRID**



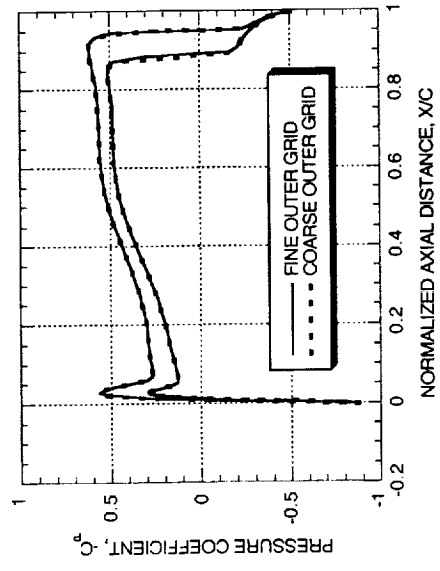
**TWO-ZONE CHIMERA GRID**



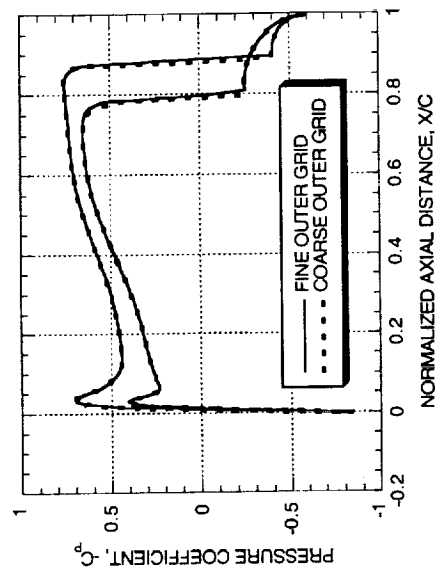
**SURFACE PRESSURE COMPARISONS  
HYBRID SCHEME, ONERA M6 WING**

$M_\infty = 0.92, \alpha = 1.0^\circ$

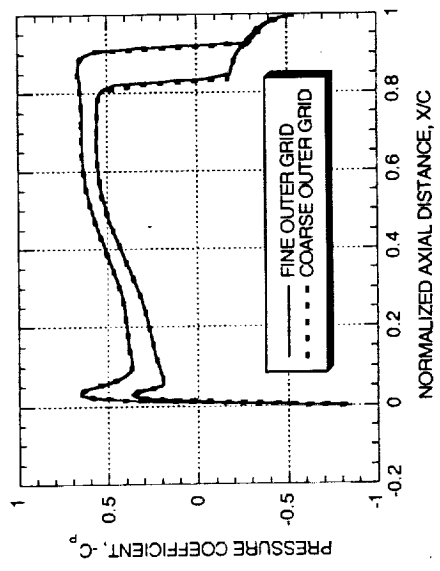
**$2y/b=0.20$**



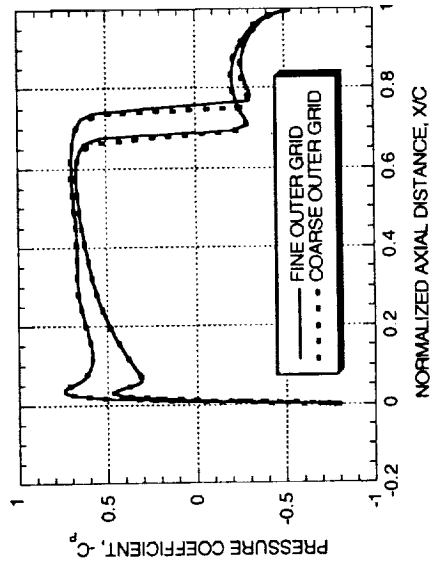
**$2y/b=0.65$**



**$2y/b=0.44$**

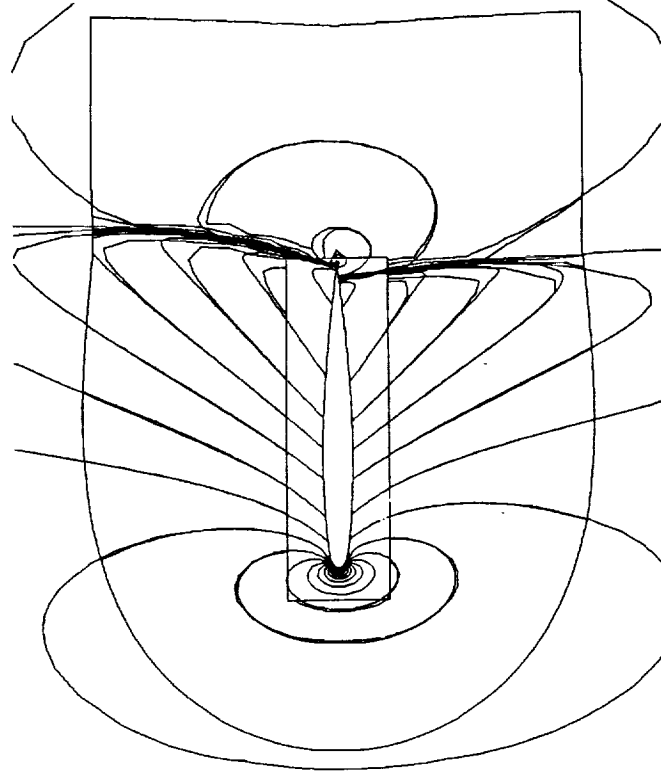


**$2y/b=0.90$**

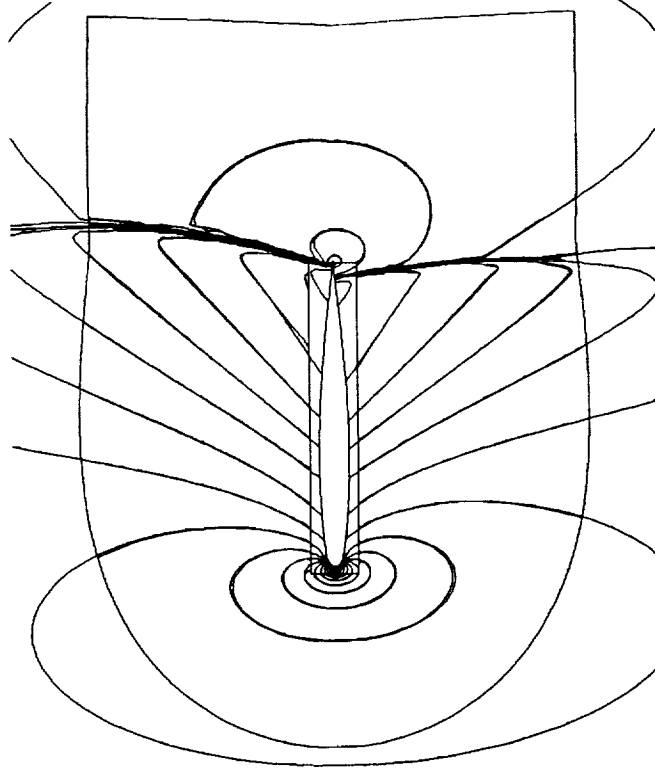


**MACH NUMBER CONTOURS**  
**WING-ROOT SYMMETRY PLANE**  
**BOTH INNER AND OUTER SOLUTIONS DISPLAYED**  
**HYBRID SCHEME, ONERA M6 WING**  
 $M_\infty = 0.92, \alpha = 1.0^\circ$

**COARSE OUTER GRID (73X33X50)**

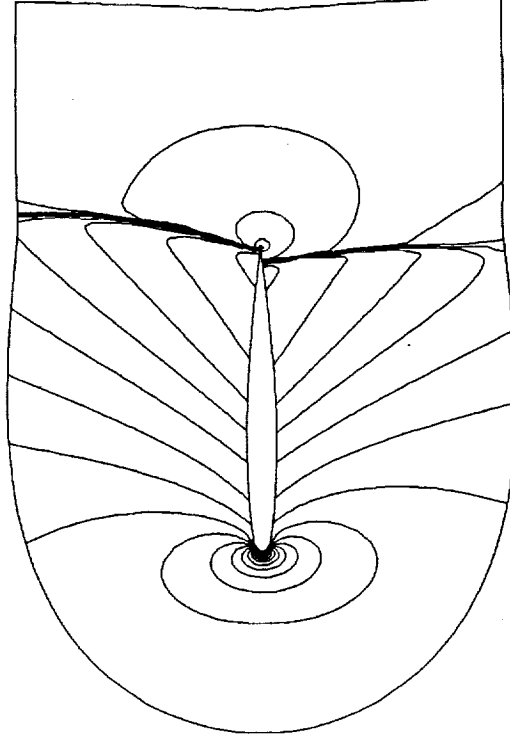


**FINE OUTER GRID (197X65X90)**

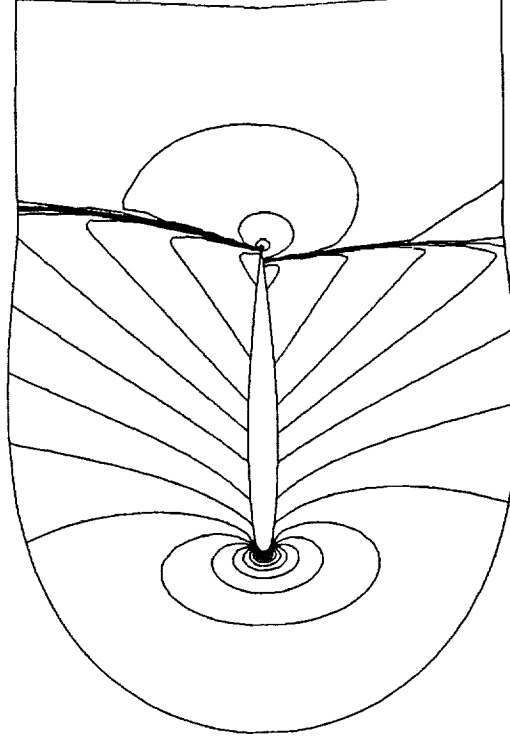


**MACH NUMBER CONTOURS**  
**WING-ROOT SYMMETRY PLANE**  
**ONLY INNER SOLUTION DISPLAYED**  
**HYBRID SCHEME, ONERA M6 WING**  
 $M_\infty = 0.92, \alpha = 1.0^\circ$

**COARSE OUTER GRID (73X33X50)**



**FINE OUTER GRID (197X65X90)**





# DONOR CELL SEARCH STATISTICS

## RAE WING A WITH B2 FUSELAGE

### THREE-ZONE GRID

WING GRID = 201X41X17, FUSELAGE GRID = 145X25X58, OUTER GRID = 101X41X62  
 IGBP = 26423

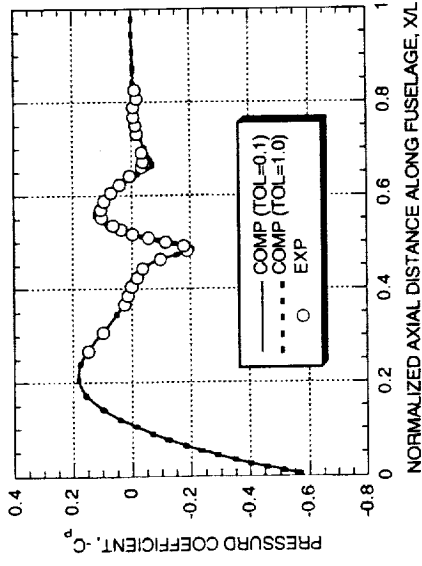
TOL	NNN	NAVG	CPU (sec)	MFLOPS
0.00	903	5.11	0.738	100
0.03	34	5.01	0.721	102
0.10	6	4.99	0.714	102
0.30	4	4.95	0.714	103
1.00	0	4.89	0.692	106

NNN - NUMBER OF NEAREST NEIGHBOR CELLS USED AS DONORS  
 NAVG - NUMBER OF DONOR CELL SEARCH ITERATIONS PER IGBP

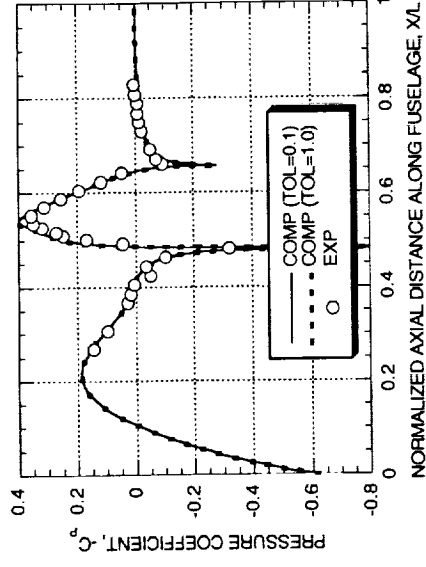
# FUSELAGE SURFACE PRESSURE COMPARISONS

RAE WING A + BODY B2,  $M_\infty = 0.82$ ,  $\alpha = 2^\circ$

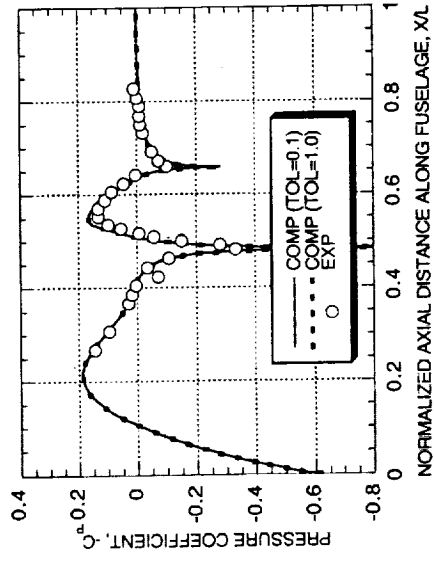
$\phi = -15^\circ$



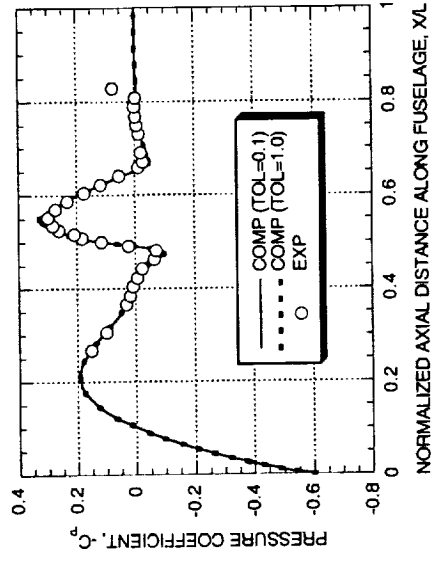
$\phi = +0^\circ$



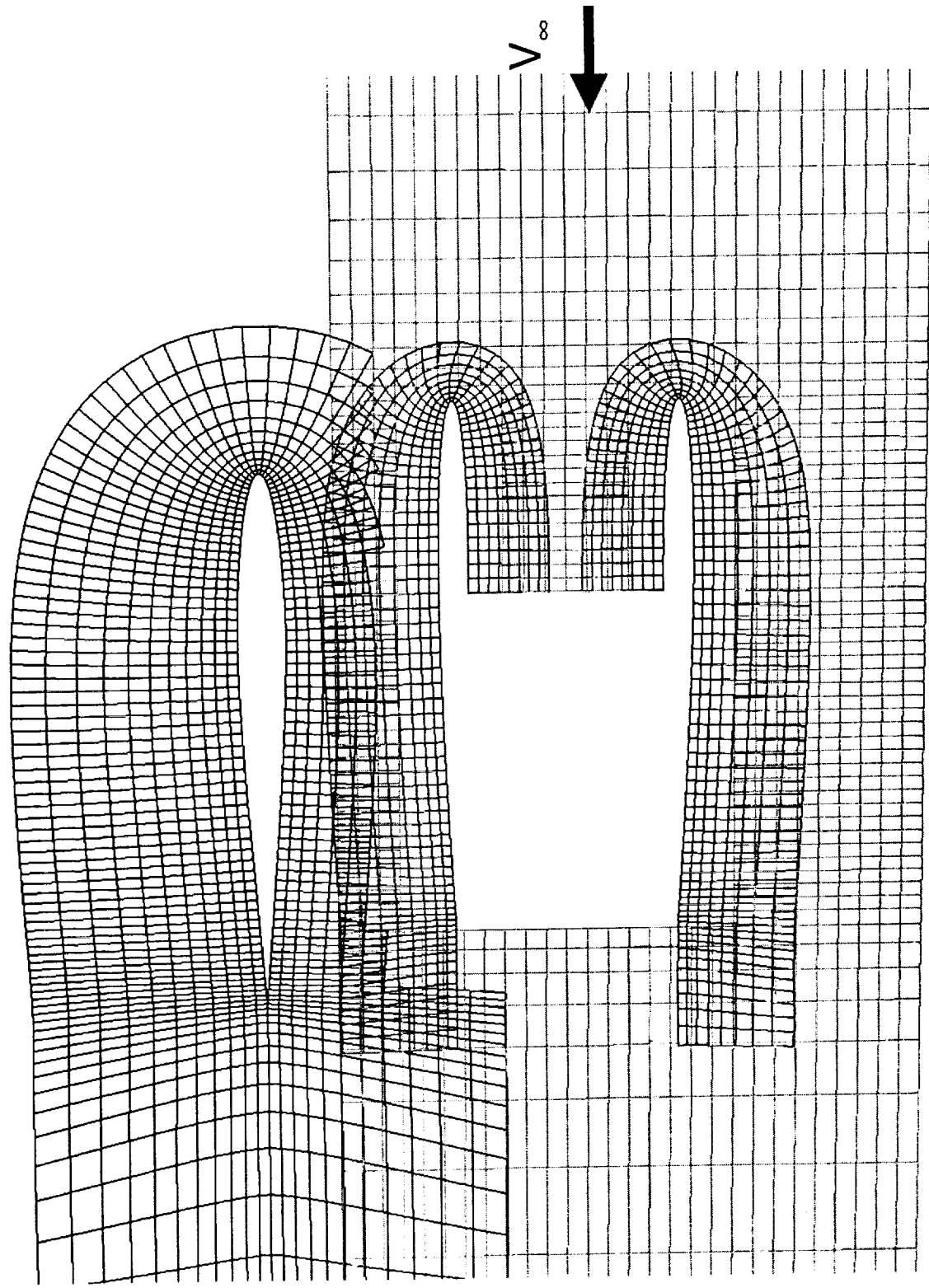
$\phi = -0^\circ$



$\phi = +15^\circ$



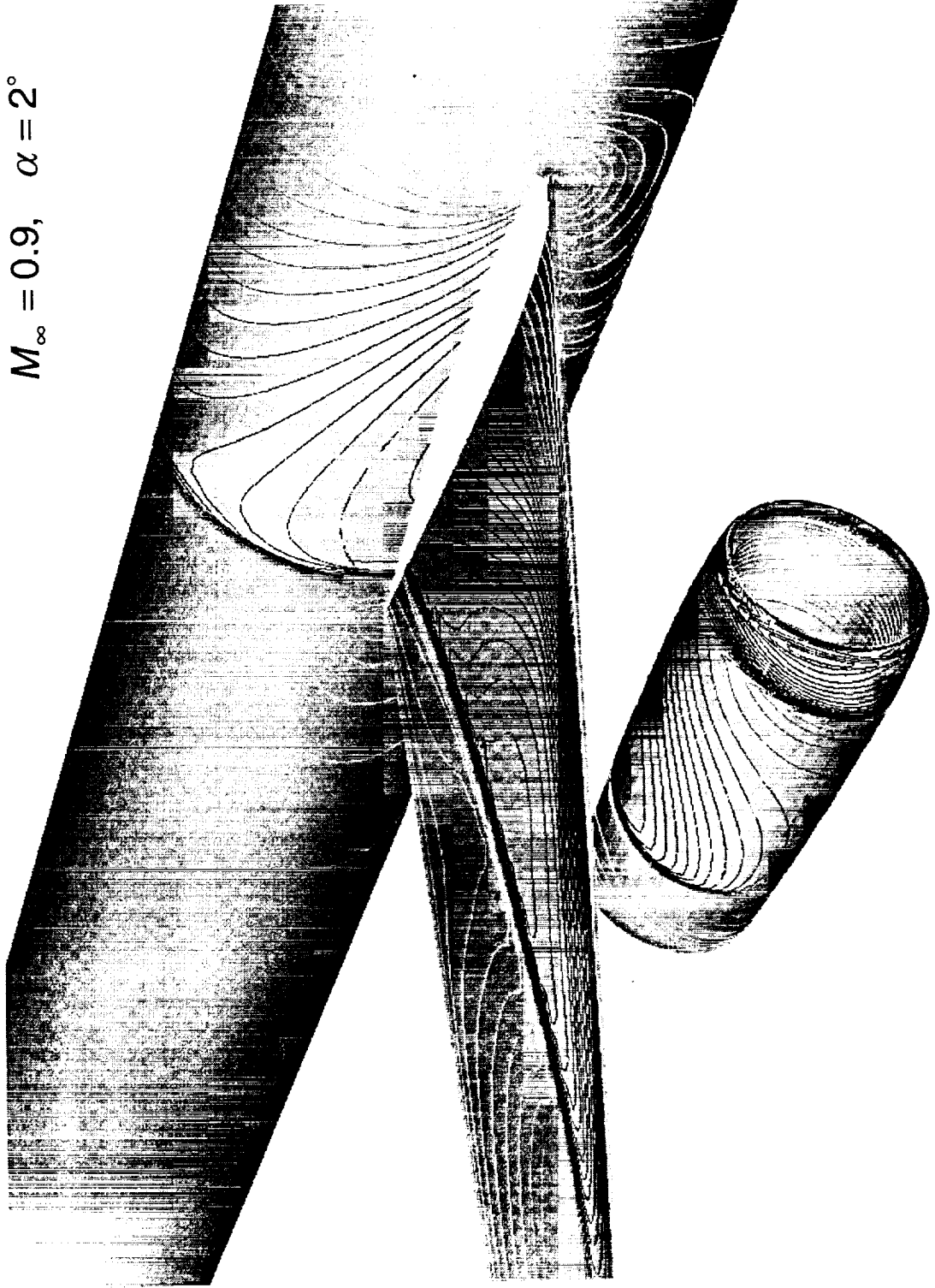
# SELECTED GRID SURFACES THROUGH NACELLE VERTICAL PLANE OF SYMMETRY



# MACH NUMBER CONTOURS

## UPPER WING SURFACE REMOVED

$$M_{\infty} = 0.9, \quad \alpha = 2^{\circ}$$



# COMPUTATIONAL STATISTICS

## NEW FRINGE POINT UPDATING

$$M_{\infty} = 0.9, \quad \alpha = 2^{\circ}$$

	Wing/Body Case	W/B/N Case
No of grid zones	3	5
Grid points	483997	689591
Fringe points	25841	56562
Computer timings (sec)		
Surface grid gen	0.01	0.01
Volume grid gen	32	36
Chimera activities	2.1	6.2
Metric computations	1.8	2.5
Flow solver		
Rmax = $10^{-8}$	427	1292
Plotable accuracy	197	540
MFLOPS rate (est)	69	69

## **CONCLUDING REMARKS**

- NEW CHIMERA-BASED FULL POTENTIAL ANALYSIS CAPABILITY HAS BEEN PRESENTED DEMONSTRATING ACCURATE NUMERICAL PREDICTION OF TRANSONIC-FLOW AERODYNAMIC INCREMENTS
- ONLY A SMALL INFLUENCE OF GRID REFINEMENT LEVEL ON THE SOLUTION NEAR SHOCKS AND ALMOST NO INFLUENCE AWAY FROM SHOCKS HAS BEEN DEMONSTRATED
- NEW FRINGE POINT UPDATING PROCEDURE HAS BEEN PRESENTED WHICH DEMONSTRATES
  - ◆ A SMALL IMPROVEMENT IN SOLUTION CONVERGENCE FOR WING/BODY CASES
  - ◆ A DRAMATIC IMPROVEMENT (UP TO X6) IN SOLUTION CONVERGENCE FOR WING/BODY/NACELLE CASES